National Green Energy Parks Transportation Program

Introduction to Biodiesel

Presented by
Charles Peterson

Emeritus Professor of Biological and Agricultural Engineering

University of Idaho

Sept. 12, 2006

- What is biodiesel?
- Advantages and disadvantages
- How much does it cost?
- UI research
- Engine warranties
- Operational issues
- Summary


Bringing agriculture and energy together

Alternative Fuels

- Ethanol
- Biodiesel
- LPG
- Hydrogen
- Fuel Cells

Biodiesel

- University of Idaho Personnel have been involved in Biodiesel Production since 1979
- The primary feedstocks have been winter rapeseed, canola and yellow mustard oils
- The fuel is made by transesterification on site
- Since 1992, over 35,000 gallons have been produced

Biodiesel Technology

Biodiesel: What it is Not?

- Unprocessed vegetable oil. **Vegetable oil can be used in some diesel engines (especially if heated) but tends to cause performance to deteriorate over time.**
- Mixtures or emulsions of alcohol with diesel fuel (E-diesel). **Major advances have been made in alleviating concerns about cetane number and lubricity. Flash point is still the primary obstacle.**


Piston ring deposits from raw vegetable oil
We don't recommend the use of raw vegetable oils

Biodiesel What it Is!

- **Technical definition from the American Society for Testing and Materials:**

Biodiesel consists of the alkyl monoesters of fatty acids derived from vegetable oils or animal fats.

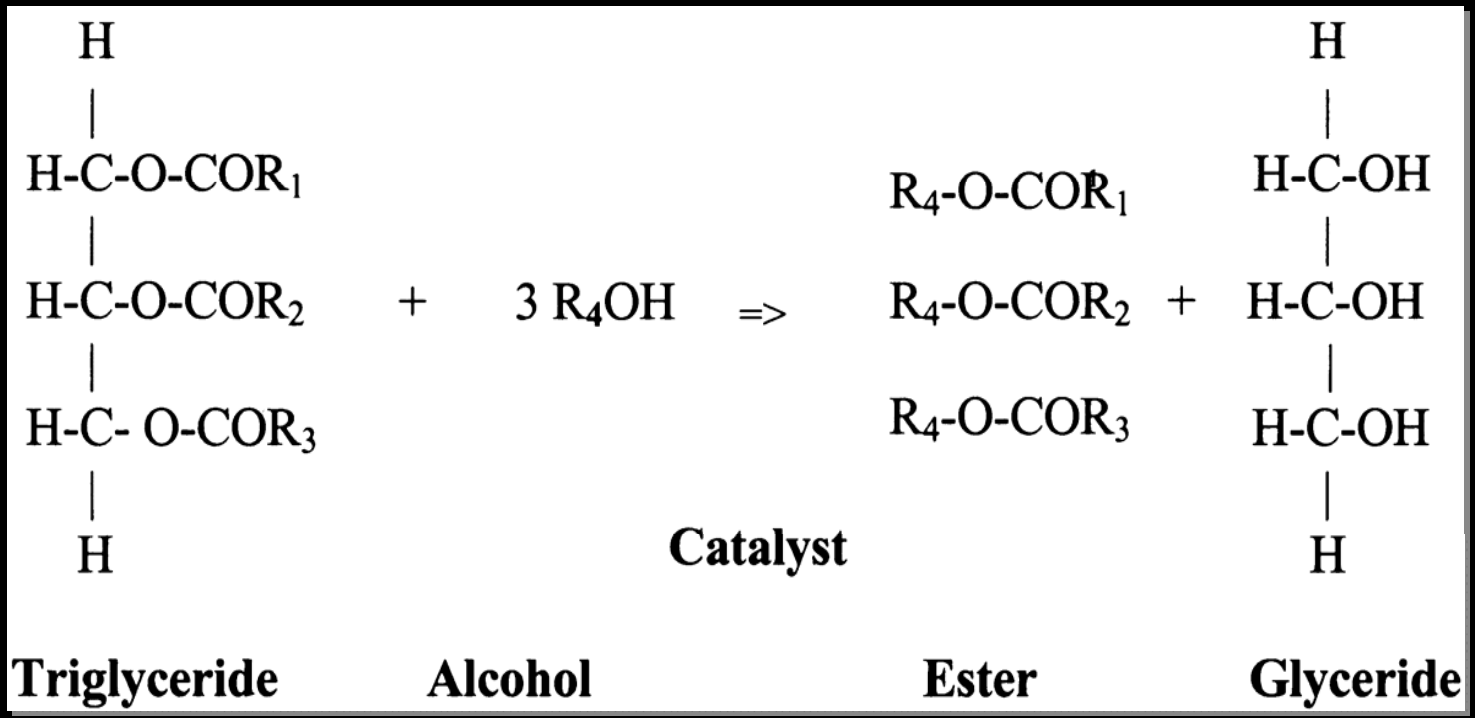
The biodiesel reaction

- Produced by a chemical reaction between methanol (or ethanol) and an oil or fat.
- 100 lb Canola oil + 10 lb methanol

  ➔100 lb biodiesel + 10 lb glycerin
- Requires a catalyst (such as Sodium Hydroxide or Potassium Hydroxide)

Transesterification Reaction

Transesterification -- uses an alcohol (methanol or ethanol) in the presence of an alkaline catalyst, such as sodium hydroxide or potassium hydroxide, to chemically cleave the raw vegetable oil molecule into methyl or ethyl esters



Advantages of Biodiesel

- Requires no engine modifications (except replacing some fuel lines on pre-1993 engines).
- Can be blended in any proportion with petroleum diesel fuel.
- High cetane number and excellent lubricity.
- Very high flashpoint (>300°F)
- Less black smoke and cleaner exhaust emissions.

Applications of biodiesel

- As a neat fuel (B100). 100% biodiesel qualifies as an alternative fuel for fleet alternatively fueled vehicle mandates.
- As a medium-level blend (B20-B50). Blends can be used to meet Energy Policy Act mandates (B20 = 1/5 vehicle).
- As a low-level blend (1% - 2%). Small amounts of biodiesel can restore lubricity to low-sulfur fuels.

Cost of Biodiesel

- Cost is very feedstock sensitive (75-80%).
- Processing cost is generally estimated to be about $0.50/gallon (small plant) to $0.30/gallon (large plant).

  Production cost = 7.6[oil price, $/lb] +$0.30

  i.e. Canola oil @ $0.28/lb gives $2.43/gal

  Yellow grease @ $0.10/lb gives $1.06/gal
- Current federal excise tax credit is $1.00/gallon
- With current incentives, biodiesel should be $1.30-$1.50/gallon (without road tax). Actual price is set by the market.

Current status of biodiesel

- In many parts of the country, biodiesel is priced below petroleum-based diesel fuel.
- Nation-wide biodiesel production in 2005 was 75 million gallons, up from 20 million in 2004.

PNW and Alaska Regional Bioenergy Program

- On-Road Testing
- Yellowstone National Park
- At Least 23 Other National Parks
- 200,000 Mile On-Road Kenworth/Cat Test

National Biodiesel Board

- Promotion
- Health Effects Testing
- ASTM Standard for Biodiesel
- Coordination


Simplot
Biodiesel


Yellow Mustard Biodiesel
Powered by Biodiesel
Biodiesel
Powered by Biodiesel

University of Idaho

- National Park Bioenergy Programs


YELLOWSTONE
NATIONAL
PARK
NATIONAL
PARK
SERVICE
Department
of the Interior
Powered by
Biodiesel
• Safe
• Clean
• Renewable
• Biodegradable
Vand-Otts

Greening of Yellowstone

- **The Yellowstone National Park project gave biodiesel a national and international exposure.**

Yellowstone Biodiesel Bus

U of I Vandal Trolley


Simplot
Caldwell, Idaho
ICCMC 167150
SPONSORS:
US DOE TRANSPORTATION TECH.
CATERPILLAR INC.
KENWORTH TRUCK CO
J.R. SIMPLOT CO.
TREBAR KENWORTH SALES
WESTERN STATES CATERPILLAR
NORTHEAST REGIONAL BIOMASS PROG.
IDAHO ENERGY DIVISION
UNIVERSITY OF CALIFORNIA, DAVIS
UNIVERSITY OF IDAHO
Powered By:
Biodiesel
* Safe
* Renewable
* Biodegradable
* Clean Burning
Ester of Used French Fry Oil)

Uses of Biodiesel

Pure fuel (B100)

Biodiesel can be used in its pure form, also known as *neat* biodiesel, or B100. This is the approach that provides the most reduction in exhaust particulates, unburned hydrocarbons, and carbon monoxide. It is also the best way to use biodiesel when its non-toxicity and biodegradability are important.

Uses of Biodiesel

Blends (typically 20-50%)

- **Biodiesel will blend with petroleum-based diesel fuel in any proportion**
- **Blends reduce the cost impact of biodiesel while retaining some of the emissions reduction.**
- **Most of the emissions reductions appear to be proportional to the percentage of biodiesel used.**

Uses of Biodiesel

As an additive, 1-2% (B02)

- **Tests for lubricity have shown that biodiesel is a very effective lubricity enhancer. Even as little as 0.25% can have a measurable impact and 1-2% is enough to convert a very poor lubricity fuel into an acceptable fuel.**
- **These levels are too low to have any impact on the cetane number of the fuel or the emissions from the engine, the lubricity provides a significant advantage at a modest cost.**

Potential Difficulties with Biodiesel

- NOx tends to be higher
- Reduced fuel filter change intervals
- Biodiesel may cause problems with loosening of varnish deposits in fuel tanks and lines, degradation of fuel lines because some elastomers are not compatible with biodiesel (such as BUNA rubbers)
- Potentially damaging to paint.
- Paving and concrete can be degraded if it is subjected to chronic exposure to biodiesel.

Disadvantages of biodiesel

- **Cold Weather Operation:** Soybean oil-based biodiesel will start to crystallize at around 0°C. This can be mitigated by blending with diesel fuel or with additives.
- **Biodiesel is less oxidatively stable** than petroleum diesel fuel. Old fuel can become acidic and form sediments and varnish. Additives can prevent this.
- **Biodiesel has been more expensive** than petroleum diesel fuel.

Engine Manufacturer's Association - EMA

- Blends up to B5 should not cause problems, provided the B100 meets ASTM D 6751
- Neat biodiesel and higher blends of biodiesel can cause a variety of performance problems
  - filter plugging, injector coking, piston ring sticking and breaking, elastomer swelling

Engine Warranties

- **Engine manufacturers warrant the parts and assembly of their engines.**
  - **They do not warrant their engines on specific fuels.**
  - **If a customer has a problem caused by the fuel, the engine manufacturer will direct them to the fuel supplier.**

Caterpillar Example - Typical

- **From Caterpillars statement on biodiesel:**

"Caterpillar neither approves nor prohibits use of biodiesel fuels….The use of biodiesel fuel does not affect Caterpillar's materials and workmanship warranty. Failures resulting from the use of any fuel are not Caterpillar factory defects and therefore the cost of repair would NOT be covered by Caterpillar's warranty."

Link to engine company warranty statements:

http://www.biodiesel.org/resources/fuelfactsheets/standards_and_warranties.shtm

Engine Manufacturers

- Engine Manufacturers Association (EMA) says that B5 is not a problem.
- Most engine companies indicate that use up to B20 is O.K. Above that, they are trying to gain more experience.
- Caterpillar says B100 is O.K. for non-Perkins engines.
- Chrysler is putting B5 into the Jeep Liberty as the factory fill (2005-2006).
- Deere is using B2 as their factory fill.

Other issues:

- When switching old fuel tanks or vehicles to biodiesel, there may be some loosening of deposits – plan to change fuel filters once or twice after fuel changes.

ASTM Specification for Quality Biodiesel

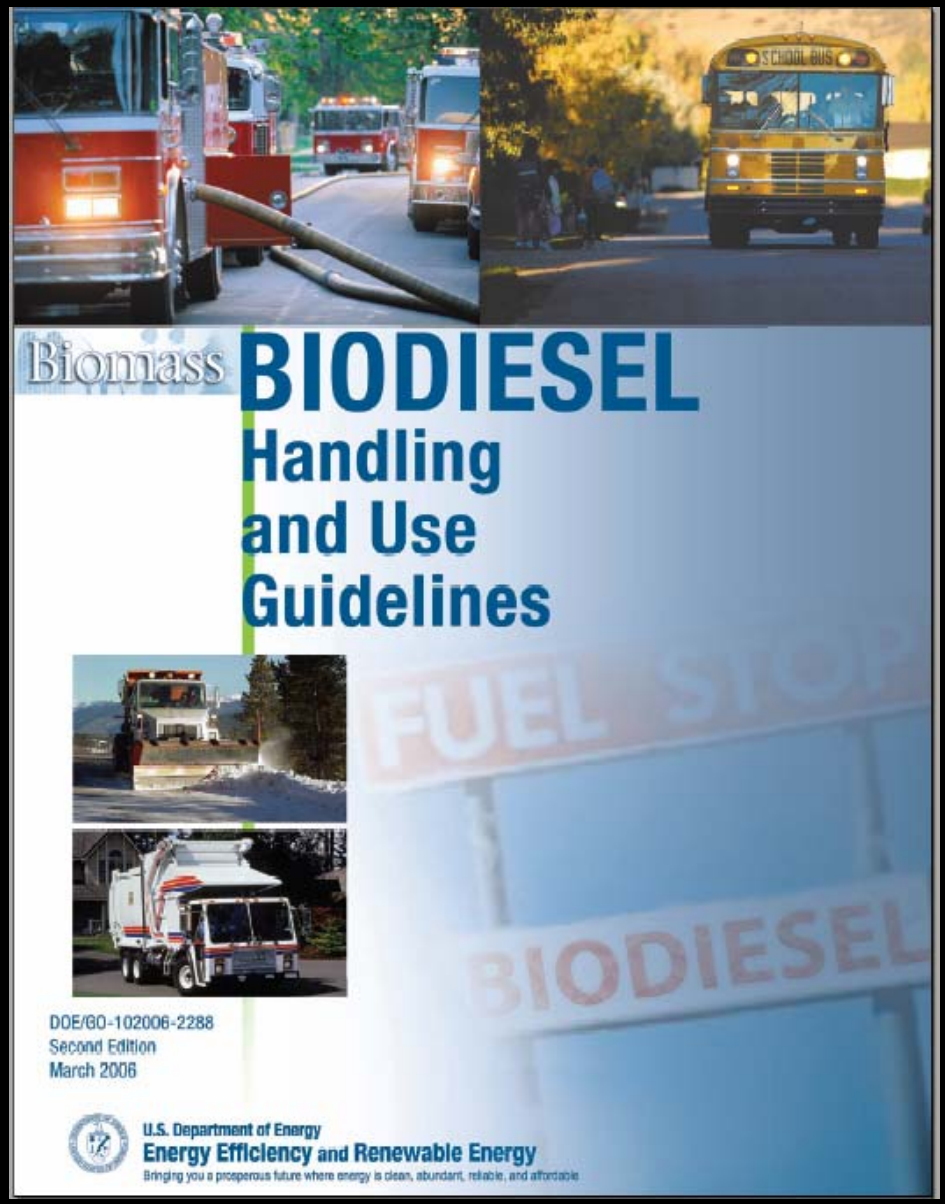
Table X - Summary of Biodiesel Fuel Standard*

PROPERTY	LIMITS	METHOD
Flashpoint	130 °C Min	D 93
Water & Sediment	0.050 % by volume max.	D 2709
Kinematic Viscosity, 40 °C	1.9 – 6.0 mm^2/s	D445
Sulfated Ash	0.020 st. % max	D874
Total sulfur	0.05 wt % max	D5453
Copper Strip Corrosion	No. 3 max	D 130
Cetane Number	47 min	D 613
Cloud Point	Report to customer	D2500
Carbon residue	0.050 wt. % max	D4530
Acid Number	0.80 mg KOH/g max	D 664
Free glycerin	0.020 wt. % max	D6584
Total glycerin	0.240 wt. % max	D 6584
Phosphorous	0.0010 wt % max	D 4951
Vacuum Distillation End Point	360 °C max at T-90	D 1160
Storage Stability	N.A.	Not yet developed

*ASTM D 6751, " Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels," ASTM International. For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

- A Three Tier Approach
  - Some properties need continuous monitoring
    - Free and Total glycerin
    - Acid Number
    - Viscosity
    - Flash point
  - Some properties should be checked regularly
    - Cloud point
    - Pour point
    - Water and sediment
    - Phosphorous
    - Total Sulfur
    - Copper strip corrosion
    - Carbon Residue
  - Some may only need evaluation when the feedstock changes
    - Cetane number
    - Vacuum distillation
    - Sulfated ash

Biodiesel Handling and Use Guidelines



The Seven Biodiesel Commercialization Questions?

1. What is the Motivation?
2. What is the source of feedstock?
3. What are your markets?
4. What are you going to do with your by-products.
5. What is your plan to meet the ASTM Specification for Quality Biodiesel?
6. Do you have a business plan that incorporates each of these?
7. Are you prepared to deal with safety issues related to biodiesel production and use?

Reasons for the Development of Biodiesel

- **There are five primary reasons for encouraging the development of biodiesel in the United States.**

  » Van Gerpen, et al.

Reasons for the Development of Biodiesel

- It provides a market for excess production of vegetable oils and animal fats.
- It decreases the country's dependence on imported petroleum.
- Biodiesel is renewable and does not contribute to global warming due to its closed carbon cycle.
- The exhaust emissions from biodiesel, except for NOx, are lower than with regular diesel fuel. Biodiesel provides substantial reductions in carbon monoxide, unburned hydrocarbons, and particulate emissions from diesel engines.
- Biodiesel has excellent lubricating properties.

ENVIRONMENTAL BENEFITS

- Emissions
- Biodegradability
- Toxicity
- CO_2 Recycling
- Reduced Sulphur
- Renewability

EPA Comprehensive Emissions Analysis for Biodiesel

	B20	B100
• NOx	+2.0%	+10%
• PM	-10.1%	-47%
• HC	-21.1%	-66%
• CO	-11.0%	-47%
• Fuel Economy(B20)		-1-2%

- **Lower energy content**

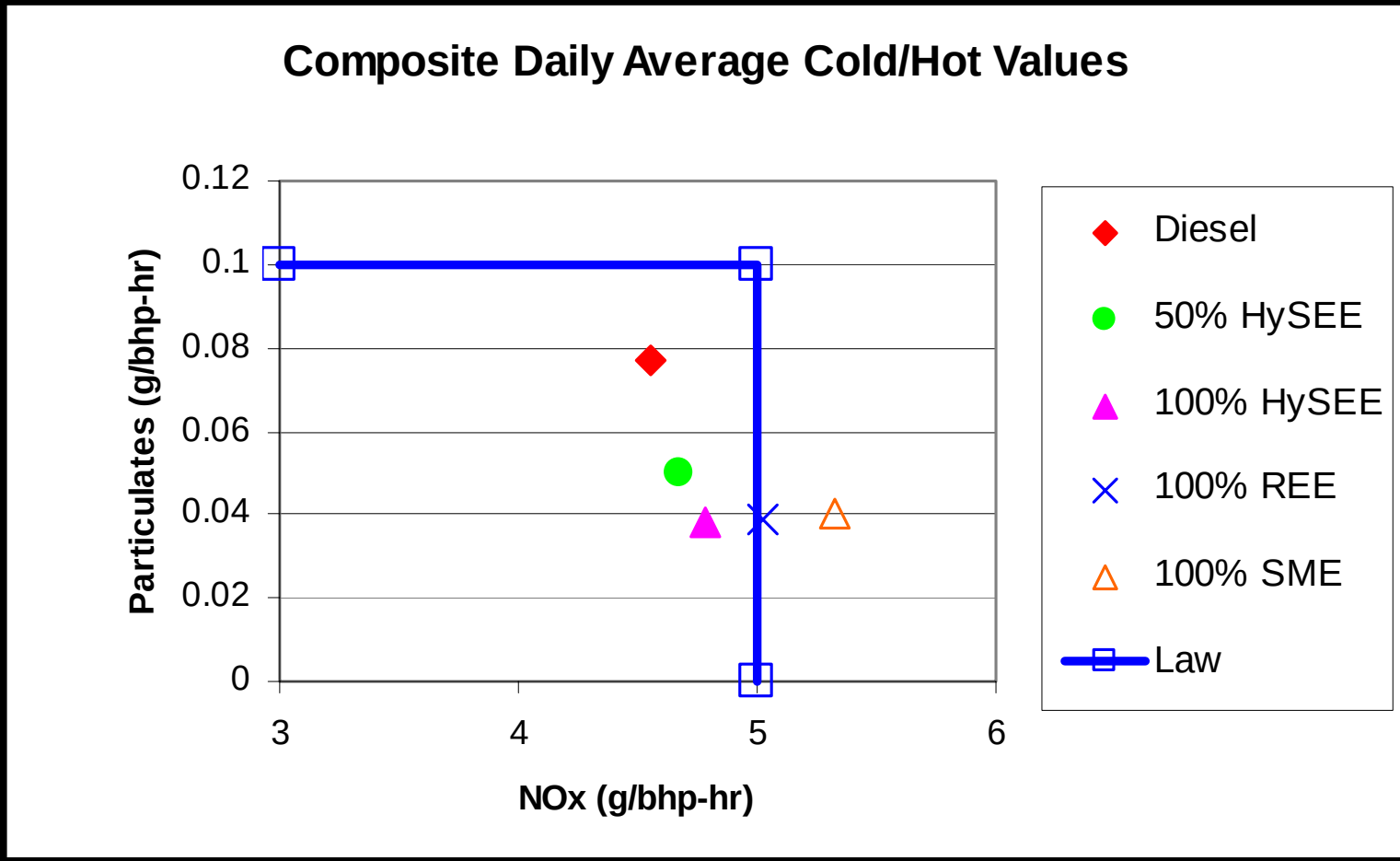
	Btu/lb	Btu/gal
No. 2 Diesel	18,300	129,050
Biodiesel	16,000	118,170
	(12.5% less)	(8% less)

- **Since diesel engines will inject equal volumes of fuel, power will drop 8% for B100.**

Emissions, Power and Fuel Consumption as a Percent of Diesel

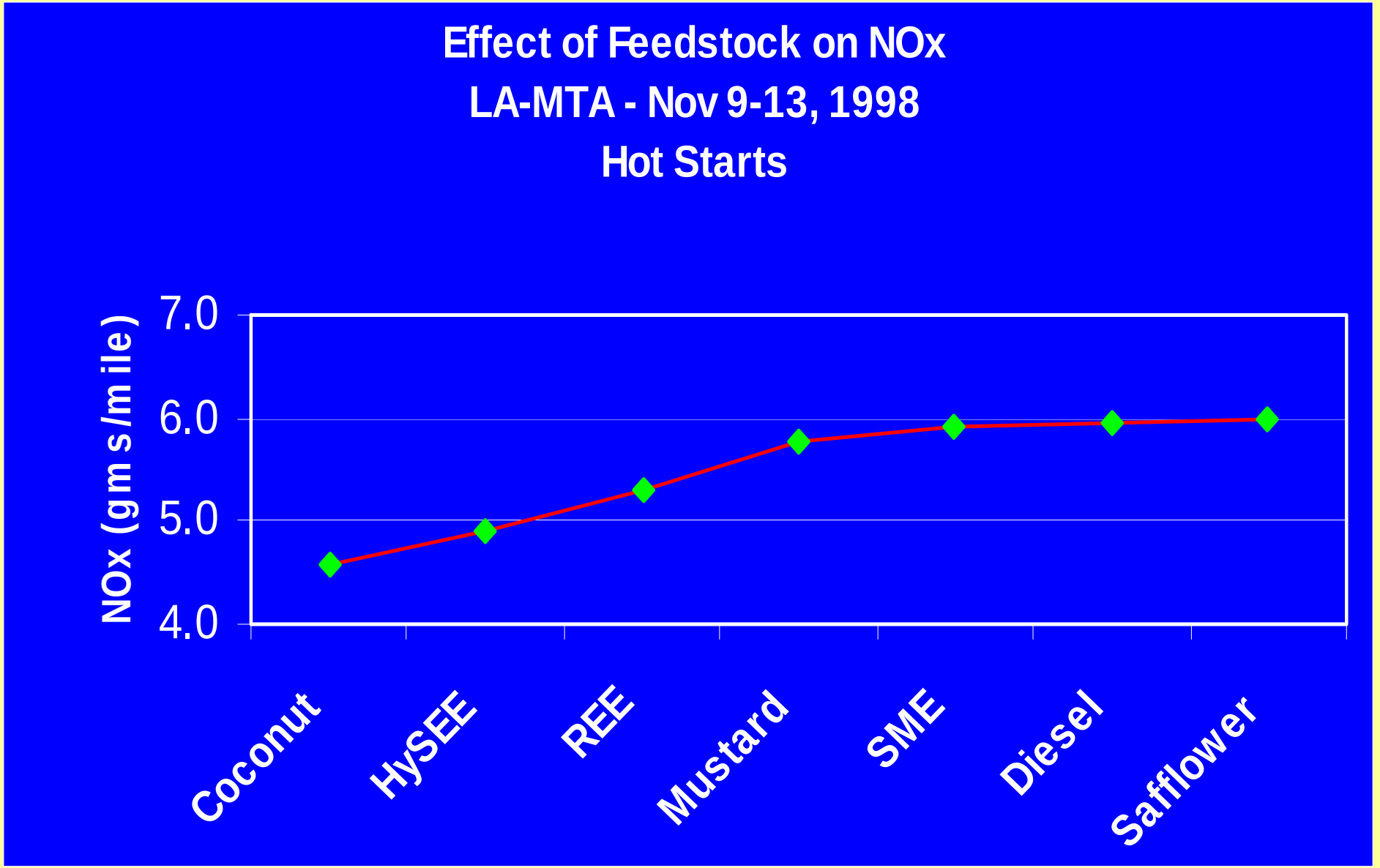
	HC %	CO %	Nox %	PM %	Power %	Fuel Rate %
50% HySEE	50.8	63.3	102.9	64.9	95.9	101.5
100% HySEE	21.6	43.3	105.0	49.4	92.3	104.5
100% REE	25.0	46.2	110.3	50.6	94.5	105.0

Smith (1998) - Caterpillar

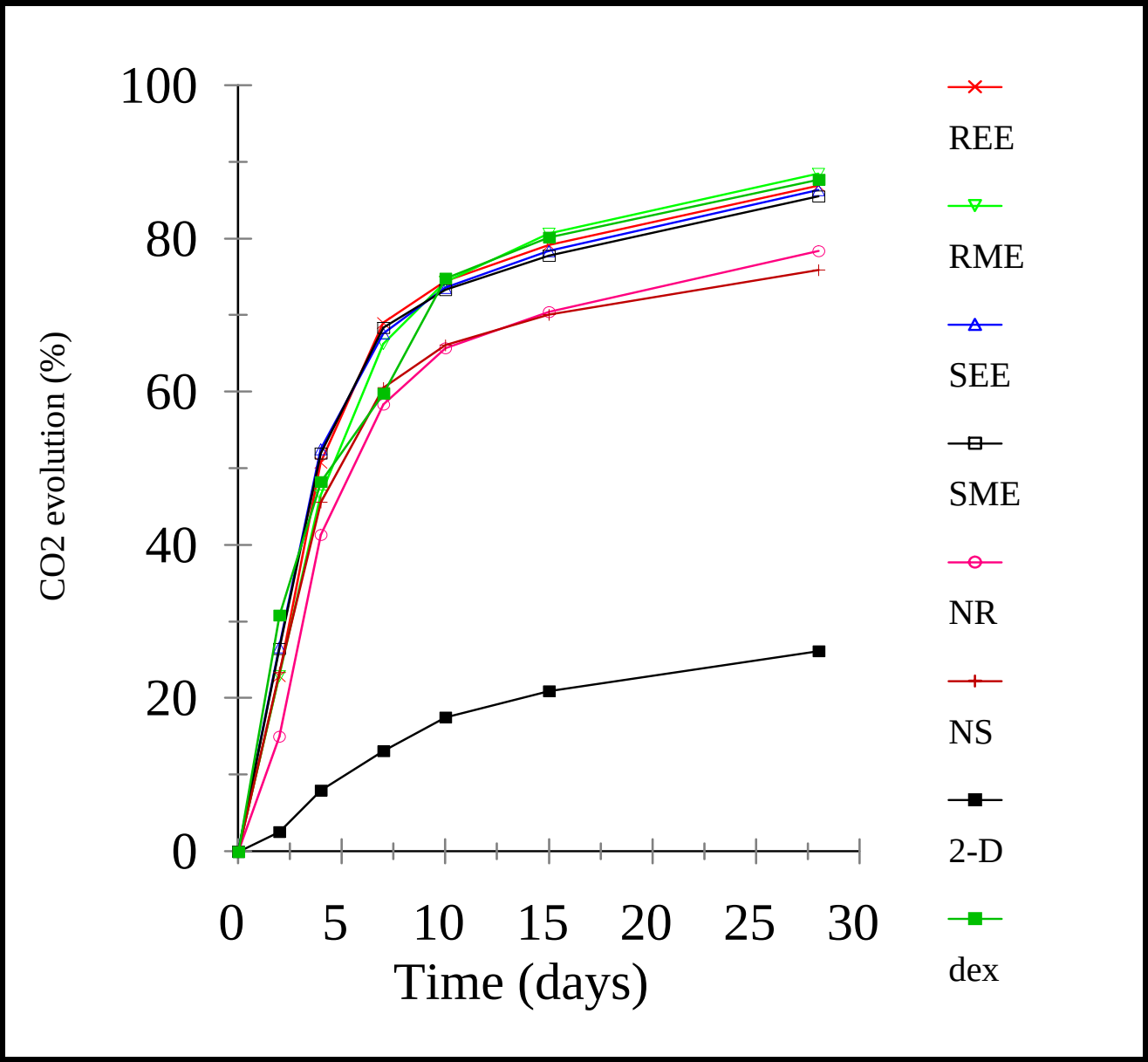


- 2007 – PM = .01 and NOx = 0.20

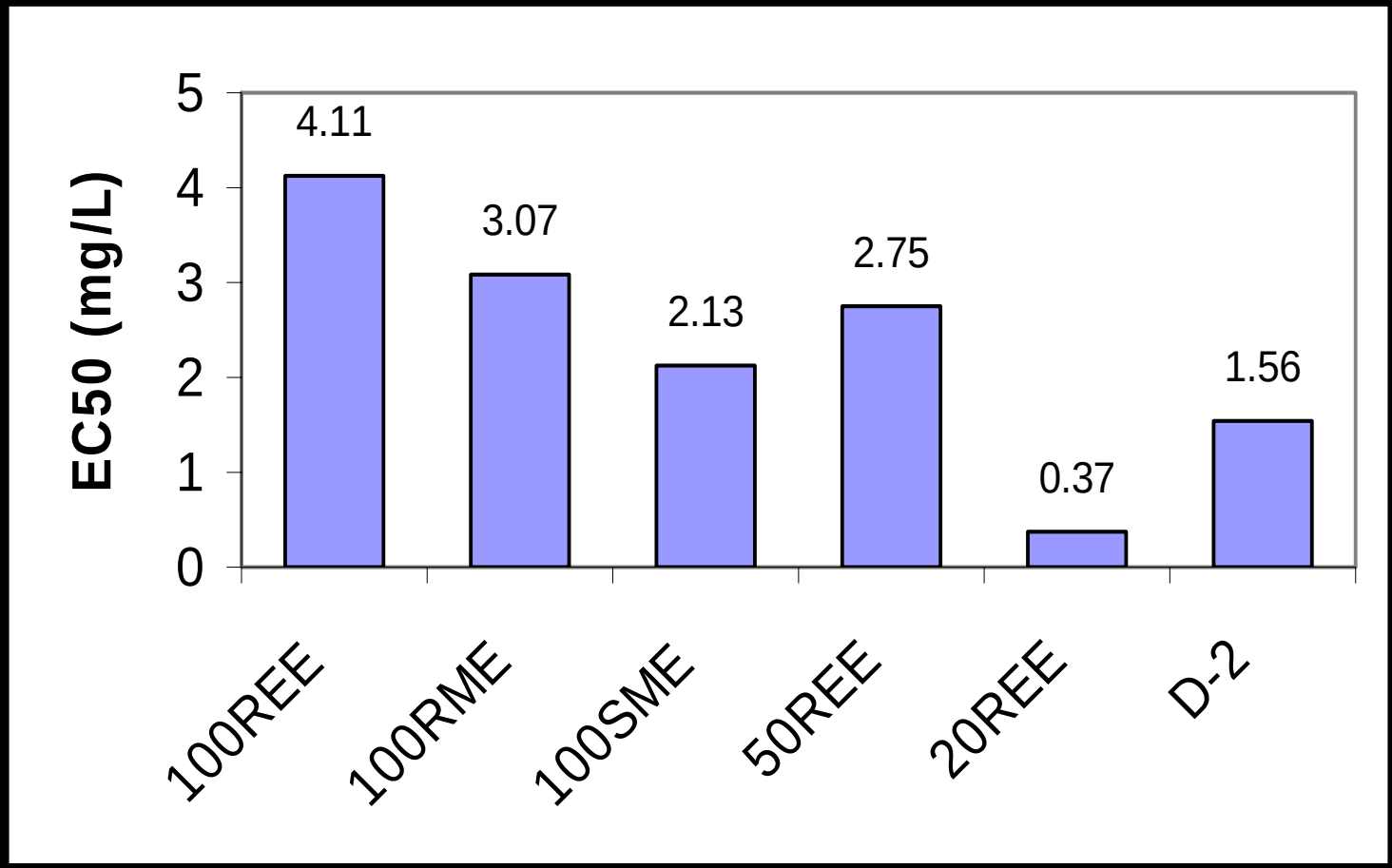
Effect of Feedstock on NOx



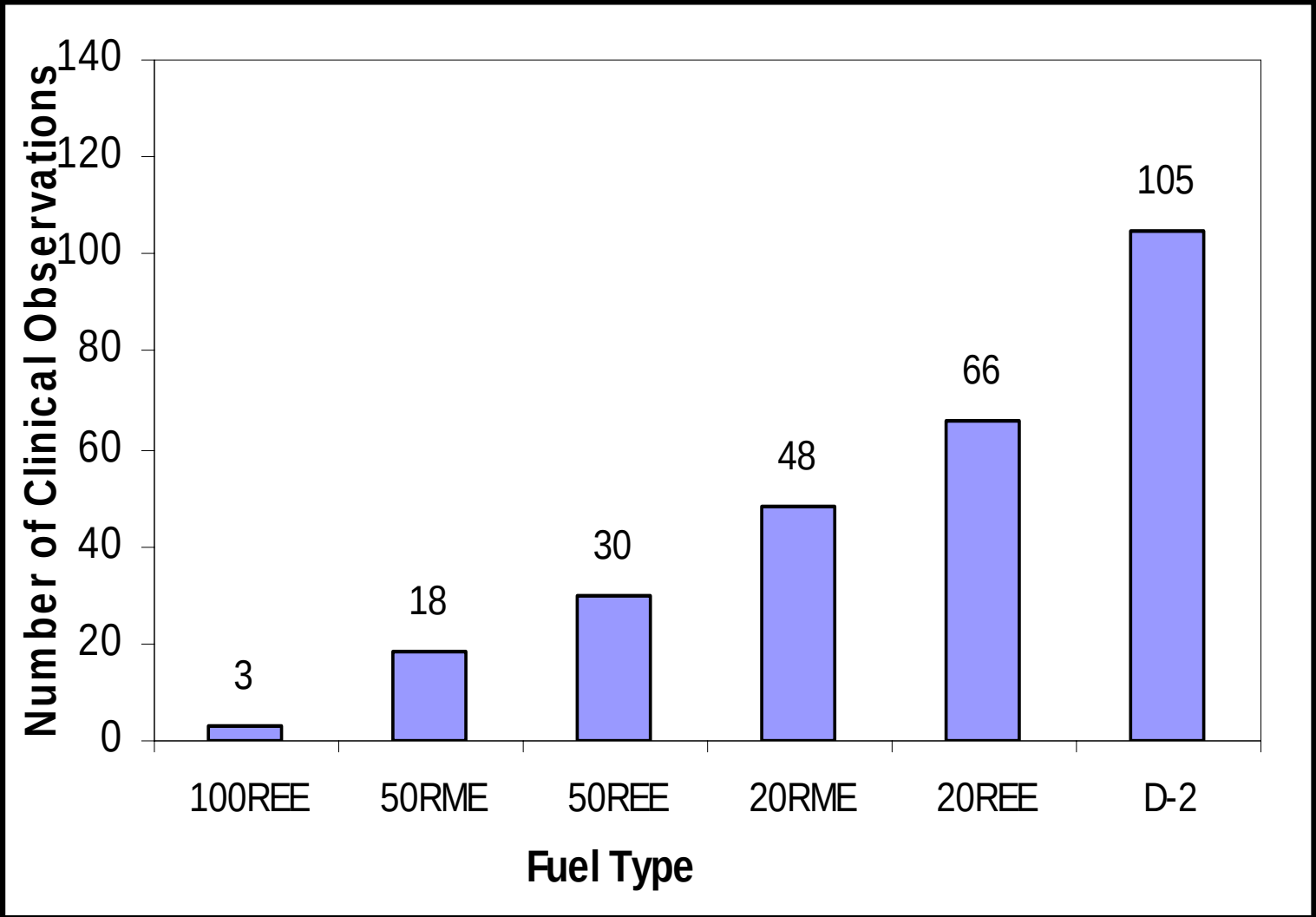
Biodegradability



48 hour Flow-through, Daphnia Magna EC50 - U of I



Number of clinical observations for each fuel type for the acute oral toxicity tests with albino rats



Bioassay Analysis of Particle Emissions

- The potency of diesel particulate matter is approximately 3 times greater than the HySEE particulate matter. Specific mutagenic activity with metabolic enzymes: mutagens (sd)
  - HySEE - 3.49* (.57)
  - 50:50 - 6.52 (2.02)
  - Diesel - 10.75 (2.58)

  *activities are reported as revertants per µl

Bioassay Analysis of Particle and Semi-volatile Emissions

- The HySEE emission rate for mutagenic compounds was approximately less than 1/3 the emission rate for diesel fuel in the particle phase and approximately 1/2 for the vapor phase.

Biodiesel Feedstocks – Sources

Annual sales of diesel fuel - Year 2000 – US only

- On-highway Diesel (billion gallons)
  - 33.13
- Off-Highway Farm
  - 2.28 3.1
- Electric Power Railroad
  - 1.13 3.0
- Military
  - 0.23
- Total Fuel Oil and Kerosene
  - 57.1

Biodiesel Feedstocks - Sources

- Virgin Oils
  - Rapeseed, canola, yellow mustard crops
  - Other specialty oil seed crops
    - safflower
    - sunflower
    - other
- Used Oil from restaurants and deli's
- Used Oil from processing plants
- Tallow

Biodiesel Feedstocks – Used Oils

- Used Oil from restaurants and deli's
  - Estimate 1.1 gallons per day per person (NREL)
  - Challenge
    - estimate the percentage that can be obtained for biodiesel use
    - current renderer's are reluctant to give up current customers to supply a new, and uncertain market such as biodiesel -- cash talks
    - Setting up a system to collect these oils would be expensive and competitive
  - Duplicating current services - significant investment
    - Trucks - Tanks - Labor - Containment

Uses for Yellow Grease

- Yellow grease goes into the manufacture of soap, makeup, clothing, rubber and detergents, its principal use is as a livestock feed additive.
- It makes the feed less dusty, which is more pleasant for the livestock, and causes less wear and tear on milling machinery.
- And, of course, it's a dense source of energy, which is important for animals like cattle and horses that have a hard time eating any more than they already do.

Biodiesel Feedstocks – Used Oils

- Used Oil from processing plants
  - information is proprietary
  - Biodiesel plant must negotiate individually
  - supply not certain because of different products and re-use strategies
  - processing plant goal is to not have waste grease
    - High quality feedstock < 3% FFA

Biodiesel Feedstocks

- **Tallow**
  - large supply
  - recent changes in livestock feed regulations prohibit this product from being used for feed
  - one of the most abundant sources of oil available in the Treasure Valley
  - current renderer's are reluctant to give up current customers to supply a new, and uncertain market such as biodiesel
    - may be negotiable

Biodiesel Feedstock - Virgin Oils

- Winter rapeseed
- Winter canola
- Mustard
- Alternative Oil Seed Crops
  - Sunflower
  - Safflower
  - Soybeans
- Other

Trap Grease, Etc.

- There are other forms of grease for sale, like brown grease or trap grease. Brown grease might come off the grill at a burger place, and is more meat-derived than yellow grease, but there's less of it and it's not as valuable as yellow grease.

Current Prices

- **Soybean Oil -- 18 – 24 cents/lb**
  $1.35 - $1.80 per gallon
- **Canola Oil – 21.25 – 24.5 cents/lb**
  $1.59 - $1.84 per gallon
- **Yellow Grease – 12 – 14 cents/lb**
  $0.90 -- $1.05 per gallon

Biodiesel Market

- **Potential customers**
  - **EPAC**
    - **State Fleets**
      - DOT
      - National guard
    - **Federal Fleets**
      - Forest service
      - BLM
      - BREC
    - **Utllities**
      - Idaho Power
      - Intermountain Gas
  - **Others**
    - **Public Transportation**
    - **Sanitation Companies**
    - **Boise City**
    - **Counties**
    - **School buses**
    - **Public**

Total Annual Production of US Fats and Oils.

- Vegetable Oil Production

	Billion Lbs	Billion Gallons
Soybean	**18.340**	**2.44**
Peanuts	**0.220**	**0.29**
Sunflower	**1.000**	**0.13**
Cottonseed	**1.010**	**0.13**
Corn	**2.420**	**0.32**
Others	**0.669**	**0.09**
Total Veg. Oil	**23.659**	**3.15**

» [from Pearl, G.G., "Animal Fat Potential for Bioenergy Use," Bioenergy 2002, The Tenth Biennial Bioenergy Conference, Boise, ID, Sept. 22-26, 2002.]

Animal Fats

	Billion Lbs	Billion Gallons
Inedible tallow	3.859	0.51
Lard & Grease	1.306	0.17
Yellow Grease	2.633	0.35
Poultry Fat	2.215	0.30
Edible Tallow	1.625	0.21
Total Animal Fat	**11.638**	**1.55**

Combined annual production of vegetable oils and animal fats

- **4.70 billion gallons of which 0.35 is yellow grease or 4.35 billion gallons net.**
- **13% of our On-Road Diesel Use**
- **140% of our On-Farm use of Diesel Fuel**

Current Annual Biodiesel Production

- 2003: 12- 20 million gallons
- 2004: 20-35 million gallons
- 2005: 75 million gallons
- 2006: estimated over 350 million gallons of plant capacity

Potential Biodiesel Production

- It would be very ambitious to have a one billion gallon per year industry – 25% of our total current production of vegetable oils and animal fats.

World Production 2002/03

	Million Metric Tonnes		Billion Gallons
• Soybeans	29.8	--	8.8
• Palm	25.4	--	7.4
• Sunflower	8.3	--	2.4
• Rapeseed	11.4	--	3.3
• Cottonseed	3.6	--	1.0
• Peanut	4.5	--	1.3
• Coconut	3.2	--	1.0
• Olive	2.3	--	0.7
• Palm Kernel	3.2	--	.9
• Total	91.8	--	27.0

World Production 2002/03

- It would require the entire world production of these vegetable oils to replace the US On-Road diesel fuel use.

Improving Production Potential

- University of Idaho plant scientists have developed yellow mustard varieties, which have the potential to significantly reduce the cost of the oil used in biodiesel production.
- This reduced cost of the oil is made possible by cultivars with specific properties remaining in the meal after the oil is removed.
- One of the potential uses for the meal is as a soil fumigant to replace chemicals currently in use today such as methyl bromide, which will soon be removed from the market due to it's toxicity.

Biodiesel is one of the few Agriculturally Produced Commodities that could not be grown in surplus

Byproduct Utilization – Meal Market

Meal Uses:

- Livestock feed
- Boiler Fuel
- Pesticide
- Disposal problem

Alternative Fuels

Byproduct Utilization - Meal Value

	Suitable for feed	Protein (%)	Value ($/ton)#
Safflower	yes	25	$120
Sunflower	yes	50	$239
yellow mustard	*	-	
Canola	*	36	$172
Rapeseed	*	36	$172

*depends on glucosinalate content

#Current price of 47% protein soy meal is $225 per ton

Byproduct Utilization - Glycerine Market

Glycerol Uses:

- Livestock feed
- Boiler Fuel
- Raw material for cosmetics, food, etc.
- Disposal problem

Glycerol Value:

- USP Grade - $0.40 per pound
- Unpurified glycerol may be a disposal problem

Glycerol Production and Use

	U. S.	Europe	Japan	Total
Annual capacity	169	315	59	543
Production	159	247	53	459
Consumption				
Personal/oral care products	75	46	15.5	136.5
Drugs/Pharmaceuticals	14	24	23	61
Foods/beverages	42	27		69
Polyether polyols	17	33	6	56
Tobacco	22	15	5	42
Alkyd resins	6	17	7.5	30.5
Other	13	79	29	121

Table 5 – Production, Consumption, and Uses of Glycerol, 2001 (in thousands of tonnes; source: Chemical Economics Handbook)

Biodiesel Safety

- There have been too many accidents with production and handling of biodiesel.
- Stems from the fact that the process appears and is simple and ignores the real hazards of producing an energy intensive product.
- Develop and follow a safety plan which acknowledges the real hazards that exist when handling these products.

Plant Size (Million Gallons Per Year) vs. Processing Cost in Thousands of $

	Yellow Grease Only	YG + Tallow	64,765 Acres @ 2200 #/acre	157,500 Acres @ 2200 #/acre
	0.5	4	11	21
Feedstock	$400	$3,340	$24,933	$55,828
Methanol	$56	$423	$1,144	$2,175
Catalyst	$36	$292	$795	$1,533
FFA	$30	$242	$242	$242
Freight	$25	$200	$550	$1,050
Crushing	---	---	$3,575	$8,690
PlantOp.	$150	$1,132	$2,736	$6,300
Total Cost	$697	$5,629	$33,975	$75,818
Cost - $/gal	$1.39	$1.41	$3.09	$3.61

Plant Size (Million Gallons Per Year) vs. Income in Thousands of $				
	Yellow Grease Only 0.5	YG + Tallow 4	64,765 Acres @ 2200 #/acre 11	157,500 Acres @ 2200 #/acre 21
Biodiesel	$1,173	$8,873	$23,974	$45,580
Glycerol	$2.7	$20.2	$54	$103
Meal	0	0	$3,432	$13,035
Total	$1176	$8,894	$27,460	$58,718
Income, $/gal	$2.21	$2.21	$2.52	$2.83
** No program incentives considered and fob plant				

Summary: Plant Size (Million Gallons Per Year) vs. Cost, Income and Profit				
	Yellow Grease Only 0.5	YG + Tallow 4	YG + T + 64,765 Acres @ 2200 #/acre 11	YG + T + 157,500 Acres @ 2200 #/acre 21
Cost - $/gal	$1.39	$1.41	$2.52	$2.83
Income, $/gal	$2.21	$2.21	$3.09	$3.61
Profit, $/gal**	$0.82	$0.80	($0.57)	($0.78)

** No program incentives considered and fob plant

Sensitivity Analysis

Table 21 Sensitivity Analysis* for Processing Cost and Net Profit or Loss Per Gallon as a function of Seed Cost Per Pound.**

Seed Cost Per Pound	11 Million Gallon Per Year Plant		21 Million Gallon Per Year Plant	
	Total Cost Per Gallon	Profit or Loss Per Gallon	Total Cost Per Gallon	Profit or Loss Per Gallon
$0.06	$2.45	$0.07	$2.70	$0.13
$0.08	$2.71	($0.19)	$3.04	($0.20)
$0.10	$2.97	($0.45)	$3.37	($0.54)
$0.12	$3.23	($0.71)	$3.71	($0.87)
$0.14	$3.50	($0.98)	$4.04	($1.21)
$0.16	$3.76	($1.24)	$4.38	($1.54)
$0.18	$4.02	($1.50)	$4.71	($1.88)
$0.20	$4.28	($1.76)	$5.05	($2.21)

*Based on data used for Table 17 with varying seed cost.

**No program incentives or marketing costs are considered.

Summary

- Biodiesel is an alternative fuel for diesel engines that can be produced from renewable, locally-grown materials.
- Biodiesel's advantages include much lower black smoke emissions. Older "smokey" engines will be greatly improved.
- Biodiesel does not void warranties.
- Biodiesel doesn't require anything special – just do those things you should have been doing all along!

Further information

www.BiodieselEducation.org

www.me.iastate.edu/biodiesel

www.biodieselbasics.com

www.biodiesel.org

Questions

The End